Dictionary memory based software architecture for distributed bluetooth low energy host controllers enabling high coverage in consumer residential healthcare environments

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Dictionary Memory based Software Architecture for Distributed Bluetooth Low Energy Host Controllers Enabling High Coverage in Consumer Residential Healthcare Environments

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***Abstract*--Technology has been seen as a possible solution to the increasing costs of healthcare and the globally aging population. It is known that many elderly people prefer to stay in their homes for as long as possible and remote monitoring can be a solution, but often such systems lack useful information or are prohibitive due to cost, ease of use/deployment and wireless coverage.**

This work presents a novel gateway software architecture based on threads being managed by dictionary memory. The architecture has been deployed in a distributed interconnected set of low-cost consumer grade gateway devices using Bluetooth Low Energy (BLE) that are positioned around the home. The gateway devices can then be used to listen, monitor or connect to BLE based healthcare sensors to continually reveal information about the user with full residential coverage. A further novelty of this work is the ability to maintain handover connections between many sensors and many gateways as a user moves throughout their home, thus the gateways can route information to/from sensors across the consumer's home network. The system has been tested in an experimental house and is now poised to be initially deployed to 100 homes for residential healthcare monitoring before any public mass consumer deployment.

I. Introduction

The global population is living longer, by 2040 the population of the United States over the age of 65 is estimated to double [1] and the population over the age of 60 in the People's Republic of China is also expected to double [2]. This global demographic change has created new challenges in the healthcare of the elderly population while requiring a reduction in healthcare costs in order to be sustainable.

II. Literature

It is known that the elderly population is accepting of technology to monitor their healthcare [3] and a wide range of residential monitoring systems exist [4]. While the interoperability of home networks for healthcare has been considered [5], home gateway solutions have been proposed [6], [7] to manage personal healthcare devices [8], [9].

This paper addresses the technology needed for residential healthcare gateways by presenting a novel software architecture based on dictionary memory that enables the creation of low-cost home gateway devices.

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III. Software Architecture

A. Permanent and run-time created management threads

Fig. 1 shows the software architecture of the gateway developed from this research. Each gateway has a network socket to communicate with other gateways in the residence and a residential router, as such the residential router can be used to access any connected BLE device (termed 'tag') in the home. The scan manager thread is used to continuously capture BLE advertisements (ADV) creating events in the primary thread containing the ADV data (MAC address, friendly name, data and RSSI). It is an application specific requirement to request to connect to any advertising tag or simply to listen. When a new BLE tag is requested to be connected to, a new thread "Tag_Manager" is created to manage each tag and pass data to/from the tag. Of importance here is that for each tag manager, entries exist in the dictionary memory that contain the data for the manager, including the instance of the tag manager thread itself. The timer thread allows the tag manager threads to poll for BLE notifications when tags are connected.

The event list contains a list of instances that create events. The event list is initialized with the external socket and scan manager thread events, and then with the addition of new connected tags new tag manager events and timer events are then appended to the event list.

B. Dictionary memory structure

The dictionary memory is initialized as empty. When the gateway attempts to make a connection, the dictionary memory is appended with a new entry that uses the MAC address as the dictionary memory key, and a 9-element tuple as the data for that key. TABLE I shows the content of the tuple. When a new tag manager thread is created, its instance pointer is placed into the tuple for the relevant tag MAC address. The relevant tuple also contains the instances of the event pipes to connect the tag manager to the primary gateway thread allowing the passing of data to and from the tag. By using the MAC address as the key in the dictionary memory structure, all the data associated with a tag, including the management threads for the tag, may be created, updated or destroyed accordingly with knowledge of only the MAC address of the tag.

Upon receiving a BLE ADV, the scan manager extracts the relevant information and creates an event for the primary thread. When it is agreed to attempt to connect to the tag, a new dictionary entry is created for the tag with string “Attempted” in the tuple. Upon a failed connection, the key is deleted, otherwise the tuple is updated with “Connected”, BLE “Manufacturer Name”, BLE “Friendly Name”, the instances for the tag manager thread for that tag, the event pipes and the event timer. The timer thread creates periodic check events to monitor for BLE Notifications, while both ends of the pipes create relevant events for when data is to be sent to the tag.

The gateway can send/receive data over its socket via the house wireless network with the house gateway for storage or an Internet connection, depending on the monitoring required. Upon a subsequent connection failing due to the tag moving to an area in the house with no reception to its current gateway, then the BLE connection times out, the entry in the dictionary (hence connection information) can be simply and immediately removed. The tag restarts advertising and can be heard by other gateways in the residence enabling another connection.

IV. Results

Gateway and wrist worn tag devices were created with commercial off-the-shelf System on Chip (SoC) incorporating BLE 4.0. The gateways were deployed in the IRC-SPHERE experimental house [10]. One gateway was placed on the upper floor at the top of the stairs and another gateway downstairs in the front room. The gateways broadcasted to each other when ADVs were heard, data to/from connections, and when tags were disconnected.

When users approach the house from the outside, the downstairs gateway detected the tag ADVs and made suitable connections. Connections were maintained throughout the downstairs of the property. When users ascended the stairs and moved to the rear of the property their tags lost connection to the downstairs serving gateway. The tags restarted advertising and the upstairs gateway took over the connection. The handover delay is a function of the stack timeout setting configured in the tag software and the time to establish a BLE connection, all of which is under the control of the tag. In these experiments a delay of 1.5 to 5s was achieved.

V. Conclusions

This paper has presented a novel software architecture for home/residential gateways based on dictionary memory to contain thread, event and data information. The architecture allows for the creation inexpensive self-managing gateways to be distributed about a home without any technical knowledge enabling continual monitoring of residents using healthcare sensors. The system is ideally positioned to address the needs of mass market remote monitoring of the elderly or frail.

Acknowledgment

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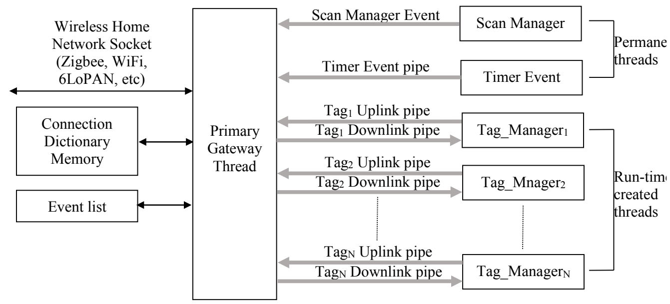

Fig. 1. Software Architecture for Gateway with external network connection socket and connection dictionary memory.

TABLE I
Dictionary Memory Structure

Key	Data
$MAC\_address_1$	String: “Attempting/Connected”,
	String: BLE “Manufacturer Name”,
	String: BLE “Friendly Name”,
	Value: Tag_manager_instance,
	Value: UL_pipe_read_instance,
	Value: UL_pipe_write_instance,
	Value: DL_pipe_read_instance,
	Value: DL_pipe_write_instance,
	Value: Timer_read_instance
$MAC\_address_2$	String: “Attempting/Connected”,
	String: BLE “Manufacturer Name”,
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